Technical Memorandum

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By:	Ray Markley, PE	**Reviewed by:** Peter H. Yuan, PE, PhD	
Tel:	(602) 733-6000	**CC:** File	
Date:	November 29, 2021		
Re:	**Stability Analysis Memorandum** **Waste Rock Facility** **Rosemont Copper World Project**		

Executive Summary

The slope stability factors of safety for the Rosemont Waste Rock Facility (WRF) meet or exceed the selected acceptance criteria defined by the Arizona Department of Environmental Quality (ADEQ) Best Available Demonstrated Control Technology (BADCT) manual (ADEQ, 2004) for all cross sections evaluated. Critical cross sections of the facility side slopes were modeled using Slide 9.012 (Rocscience, 2020) limit equilibrium software to assess slope stability under static and earthquake conditions (pseudo-static). The design seismic event with a return period of 2,475 years was selected for the WRF, which is more conservative than that of the previous WRF analysis (Tetra Tech, 2010).

The proposed WRF will be constructed to a maximum height of 820 feet. The waste rock will be constructed with maximum lifts of 100 ft, stacked at the angle of repose, with benching to create an overall slope of 2.2 horizontal to 1 vertical (2.2H:1V) and inter-lift slope of about 2H:1V. The foundation materials range from weathered rock to 80 ft of alluvial or colluvial soils overlying weathered rock. These materials are dense and dry enough that such the possibility of liquefaction of the foundation or waste rock is very low given the tectonic environment of the Rosemont Copper World Project area. The locations of the cross sections analyzed are shown in Figure 1 and the cross sections themselves are presented in Figure 3 through Figure 8.

1.0 Introduction

1.1 Purpose

Wood Environment and Infrastructure Solutions, Inc. (Wood) has prepared this technical memorandum for Rosemont Copper Company (Rosemont) to address the stability analyses in support of the Aquifer Protection Permit (APP) Application and Pre-Feasibility Study (PFS) Level Design Phase of the Waste Rock Facility (WRF) for the Rosemont Copper World Project (Project).

The data presented in this memo addresses the limit equilibrium slope stability analyses performed to assess the slope stability of WRF planned to support a PFS level design for the Project. Critical cross sections of

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the facility side slopes were modeled using Slide 9.012 (Rocscience, 2020) limit equilibrium software to assess slope stability under static and earthquake conditions (pseudo-static).

1.2 Background Information

Numerous reports have been prepared as part of the previous permitting process for the Project studies including the following key studies related to design of WRF:

- Initial geotechnical site investigations conducted in 2006-2007 at the Rosemont Copper Project (Tetra Tech, 2007)
- A detailed engineering and permitting design of a Dry Stack Tailings Storage Facility for the Rosemont Copper Project (AMEC Earth & Environmental, Inc [AMEC], 2009)
- An addendum to the 2007 Geotechnical Study report (Tetra Tech, 2009)
- A summary of additional sampling and testing performed on tailings and waste rock for the Rosemont Copper Project (AMEC, 2010)
- A technical memorandum presenting a stability analysis for the Waste Rock Storage Area at the Rosemont Copper Project (Tetra Tech, 2010)

Many of the materials used in this analysis will be the same as those used in previous studies. Additionally, Wood has completed geotechnical investigations and laboratory testing in and near the Tailing Storage Facilities (TSFs)/Heap Leach Facility (HLF)/WRF sites as part of the design process (Wood, 2021). The investigation included field mapping, test pit excavation, borehole advancement, and field and laboratory testing. The historical and new data form the basis of the WRF design.

2.0 Design Criteria

The minimum acceptable factors of safety (FoS) defined by the individual BADCT criteria for the WRF were selected. The BADCT minimum required FoS from Tables E-1 and E-2 specifies that if the potential for discharge exists, stability analyses should be performed, and the FoS should meet the same criteria as for Dump Leach Piles (ADEQ, 2009). The geotechnical design criteria for the stability analyses are presented in Table 2-1 and assume material testing has been performed.

Table 2-1: Geotechnical Slope Stability Design Criteria for Facility Design

Loading Conditions	Analytical Method	Criteria
Static	Two-dimensional limit equilibrium analysis.	FoS = 1.3
Pseudo-Static	Two-dimensional limit equilibrium analysis with an earthquake static thrust of 0.04g, corresponding to the maximum probably earthquake (MPE) design event.	FoS = 1.0

3.0 Stability Analyses

The Pre-Feasibility level design of the WRF considered field and laboratory test data from the geotechnical investigation by Wood and historical data as listed in Section 1.2. Subsurface conditions for the stability model were developed from field data presented in the Geotechnical Site Investigation Memorandum (Wood, 2021) and the previous studies. Material properties used in the analysis were developed from the

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engineering material shear strength data based on the field and laboratory investigations, available literature, and Wood's experience with similar materials.

Two-dimensional limit equilibrium method of slices was used to analyze the stability of the WRF under static and earthquake (pseudo-static) conditions. Stability analyses considered the end of the Project when the material depositions are at their respective final configurations.

3.1 Limit Equilibrium Method

A series of stability analyses were performed using Slide 9.012 (Rocscience, 2020), a commercially available computer program which enables the user to conduct limit equilibrium slope stability calculations by a variety of methods and search routines. For the failure mechanisms considered in the analyses, the slope stability was evaluated using limit equilibrium methods based on Morgenstern-Price's method of analysis (Morgenstern-Price, 1965). Morgenstern-Price's method is a method of slices (consideration of potential failure masses as rigid bodies divided into adjacent regions or "slices," separated by vertical boundary planes) that satisfies both moment and force equilibrium. Circular failure surfaces were evaluated.

The method used to evaluate the stability of the WRF was based on the principle of limit equilibrium (i.e., the method calculates the shear strengths that would be required to just maintain equilibrium along the selected failure plane, and then determines a safety factor by dividing the available shear strength by the equilibrium shear stress). Consequently, safety factors calculated by the limit equilibrium method indicate the percent by which the available shear strength exceeds, or falls short of, that required to maintain equilibrium. Therefore, safety factors in excess of 1.0 indicate stability and those less than 1.0 indicate instability. The greater the mathematical difference between a safety factor and 1.0, the larger the margin of safety (for safety factors in excess of 1.0), or the more extreme the likelihood of failure (for safety factors less than 1.0).

Slope failure geometries were evaluated considering circular slide surfaces and under both static and simulated earthquake (pseudo-static) analyses. The foundation materials will be composed of either weathered rock, or alluvium overlying competent rock which is dense and unsaturated, making the possibility of liquefaction very low given the tectonic environment of the site.

For the WRF, the stability analyses were performed assuming massive saturation zones should not develop within the WRF due to the free drainage characteristics of waste rock. The foundation materials will remain unsaturated. Excessive pore pressures are not anticipated and should not affect the stability of the WRF.

Stability analyses were performed for circular surfaces using a variety of search methods. These methods provide powerful algorithms in which the search for the lowest safety factor is refined as the analysis progresses. An iterative approach is used, so that the results of one iteration, are used to narrow the search area on the slope in the next iteration.

3.2 Earthquake (Pseudo-Static) Slope Stability Coefficient

Pseudo-static-based analyses are commonly used to apply equivalent seismic loading on earthfill structures. In an actual seismic event, the peak acceleration would be sustained for only a fraction of a second. Actual seismic time histories are characterized by multiple-frequency attenuating motions. The accelerations

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produced by seismic events rapidly reverse motion and generally tend to build to a peak acceleration that quickly decays to lesser accelerations. Consequently, the duration that a mass is actually subjected to a unidirectional, peak seismic acceleration is finite, rather than infinite. The pseudo-static analyses conservatively model seismic events as constant acceleration and direction (i.e., an infinitely long pulse). Therefore, it is customary for geotechnical engineers to take only a fraction of the predicted peak maximum site acceleration when modeling seismic events using pseudo-static analyses (Hynes-Griffin and Franklin, 1984). The pseudo-static analysis incorporated a pseudo-static coefficient of 0.04g which is 1/2 of the design Peak Ground Acceleration (PGA) of 0.07g (corresponding to the 2,475-year return period), in accordance with the design criteria and Hynes-Griffin and Franklin (1984).

A Site-Specific Seismic Hazard Study was carried out by LCI (2021). The design seismic event with a return period of 2,475 years was selected for the WRF. Selection of this design seismic event is conservative for a WRF design and appropriate to support both operational and closure designs.

The pseudo-static analyses were used to determine the FoS under simulated earthquake conditions. The pseudo-static FoS limit equilibrium slope stability method is used as a screening tool to determine if more rigorous dynamic analyses is needed to model the stability of the facility slopes under earthquake conditions. More detailed deformation analyses would be required if the slope stability FoS did not meet the acceptance criteria (less than 1).

Cyclic softening or liquefaction are not anticipated at the Project site given the subgrade and the WRF will not be saturated.The waste rock is composed or free draining material and the foundation is composed of relatively thin layers of dense alluvium overlying competent rock or competent weathered rock. The seismicity of the site is also relatively low as explained by the Site-Specific Seismic Hazard Study (LCI, 2021).

3.3 Cross Sections

Cross sections were prepared for the WRF based on survey and mine plan data obtained from Rosemont. The selected sections along the representative configurations of the WRF are shown in Figure 1. Typical geometry of the WRF consists of native soils overlain with waste rock. Slope geometries of the cross sections used in analysis are provided in Figure 3 through Figure 8.

3.4 Material Properties

The material properties used in the stability analyses for different soil layers were estimated based on boring logs, previous investigations by Wood, AMEC (a precedent company of Wood) and other parties, as well as literature data. The foundation material consists, in general, of alluvium (including GP, SP and SW soil types), highly to completely weathered rock, and moderate to slightly weathered rock. To simplify the model assumptions and material properties, the foundation material was conservatively considered to be an alluvial/colluvial soil for the entire foundation depth evaluated, consistent with the past designs of HLF/TSF/WRF (Tetra Tech, 2007; AMEC, 2010; Tetra Tech 2010).

Considering the dense nature of the material, results of direct shear tests on remolded soil samples were used to represent the Foundation Soil. Figure 2 presents a summary of shear strengths tested on remolded foundation soils of HLF/TSF, along with the strength envelope used for stability modeling. The comparison

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shows that an effective-stress strength represented by a cohesion of 0 pounds per square foot (psf) and a friction angle of 36 degrees is conservatively representative of Foundation Soil.

Strength of waste rock is represented by a cohesion of 0 pounds per cubic feet (pcf) and an internal friction angle of 37 degrees. This is a conservative assumed strength value for typical weak rockfills. The friction angle of 37 degrees used herein is slightly lower than that used in 2009 by AMEC (i.e., 38 degrees), considering that waste rock is placed in higher lifts.

The stability analysis concepts, and material properties were developed from an evaluation of the proposed waste rock properties. Drained analysis (effective-stress analyses) was performed based on the assumption that excess pore pressures will not be generated by the shearing process; the analysis method is appropriate for the coarse material that will compose the WRF. The relevant material properties for the stability analysis are presented in Table 3-1.

Table 3-1: Modeled Parameters for Drained Analysis of Waste Rock

Soil Type	Unit Wt. (pcf)	Strength Model	Friction Angle (degrees)	Cohesion (psf)	Water Table Present
Waste Rock	125	Mohr-Coulomb	37	0	No
Foundation	125	Mohr-Coulomb	36	0	No

Note: pcf = pounds per cubic feet; psf = pounds per square foot

3.5 Summary of Stability Analysis Results

For the WRF, the FoS for the static condition was calculated to be greater than 1.3, and the FoS for the pseudo-static condition was greater than 1.0. This analysis considered the overall slope angle. Individual lifts placed at the angle of repose will have a FoS of about 1.0 which is usually acceptable for the temporary construction condition. Results of the static and pseudo-static stability analyses are presented on Figure 3 to Figure 8. A summary of the calculated FoS values is presented in Table 3-2.

Table 3-2: Results of Stability Analyses

Facility Section	Factor of Safety	
	Static	Pseudo-Static
WRF01	1.44	1.31
WRF02	1.36	1.24
WRF03	1.59	1.44

4.0 Conclusion And Discussions

All FoS meet or exceed the minimum design criteria for static and pseudo-static loading conditions. However, the cross sections and material properties used for the analyses should be verified during

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production and construction. Verification should include instrumentation and construction quality control testing.

5.0 References

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AMEC, 2010. *Physical and Mechanical Properties of Tailings and Waste Rockfill Materials,* prepared for Rosemont Copper Company, by AMEC Earth & Environmental, Inc, August 23.

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Wood, 2021. *Geotechnical Site Investigation, Rosemont Copper World Project, Pima County, Arizona,* prepared for Rosemont Copper Company, by Wood Environment & Infrastructure Solutions, Inc, November 10.

Figures:

Figure 1 – WRF Slope Stability Sections Site Plan
Figure 2 – Summary of Direct Shear Tests on Foundation Soils
Figure 3 – Section WRF01 –Static
Figure 4 – Section WRF01 –Pseudo-Static
Figure 5 – Section WRF02 –Static
Figure 6 – Section WRF02 –Pseudo-Static
Figure 7 – Section WRF03 –Static
Figure 8 – Section WRF03 –Pseudo-Static

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Acronyms and Abbreviations

ADEQ	Arizona Department of Environmental Quality
AMEC	AMEC Earth & Environmental, Inc
APP	Aquifer Protection Permit
BADCT	Best Available Demonstrated Control Technology
FoS	Factors of Safety
GP	Poorly-Graded Gravels, Gravel-Sand Mixtures, Little or No Fines
HLF	Heap Leach Facility
LCI	Lettisci Consultants International
MPE	Maximum Probably Earthquake
pcf	Pounds Per cubic Feet
PFS	Pre-Feasibility Study
PGA	Peak Ground Acceleration
psf	Pound per Square Foot
Project	Rosemont Copper World Project
Rosemont	Rosemont Copper Company
SP	Poorly-Graded Sands, Gravelly Sands, Little or No Fines
SW	Well-Graded Sands, Gravelly Sands, Little or No Fines
TSF	Tailings Storage Facility
Wood	Wood Environment & Infrastructure Solutions, Inc.
WRF	Waste Rock Facility

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FIGURES

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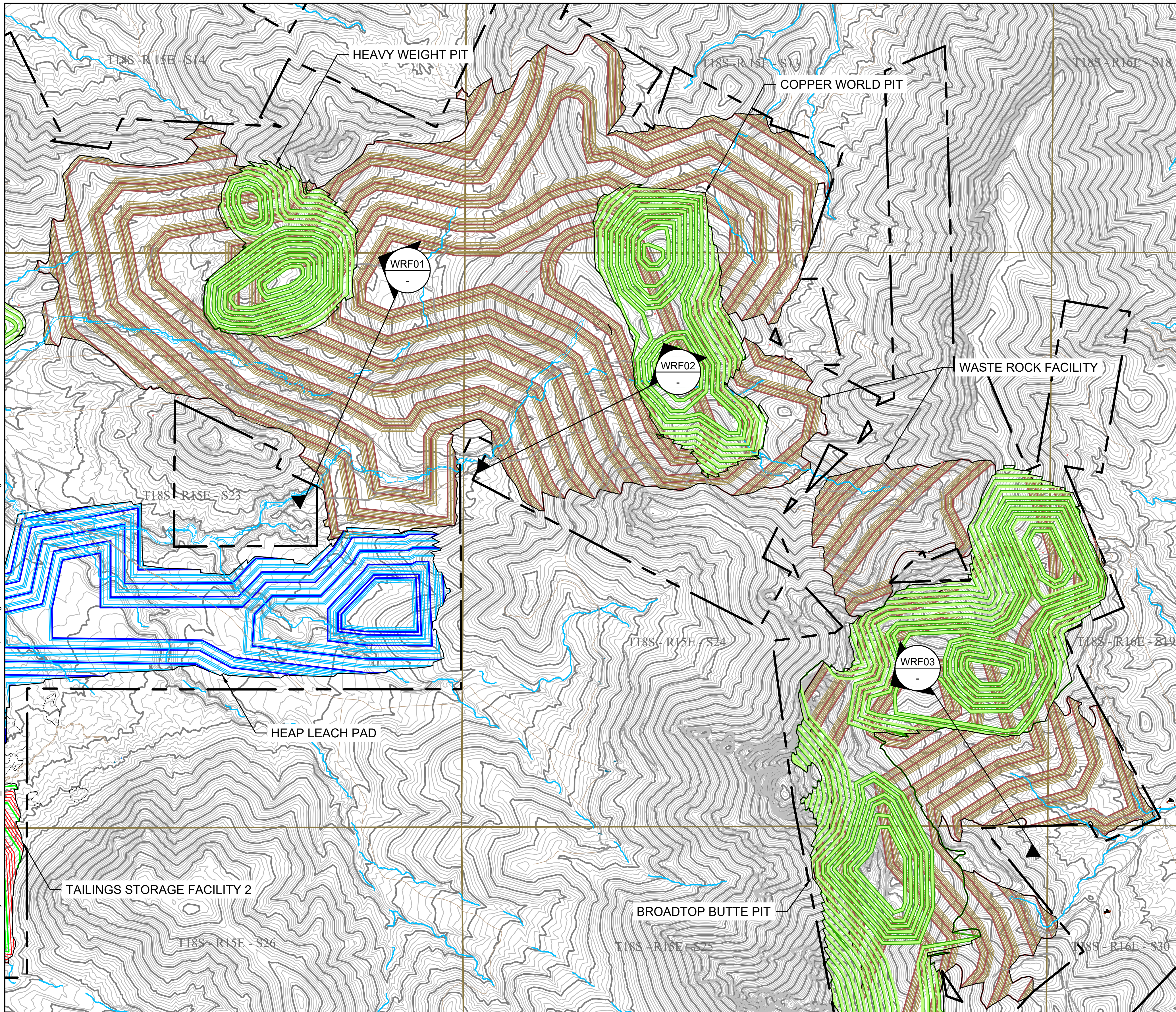

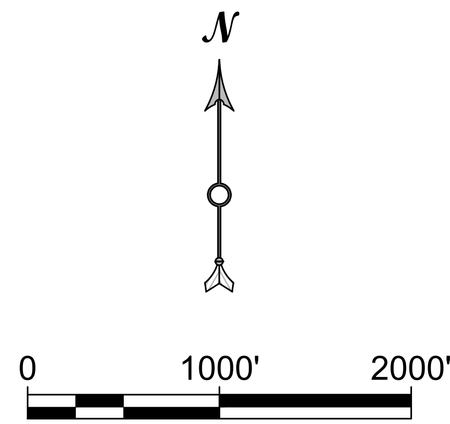

SITE PLAN

SCALE: 1"=1000'

ROSEMONT COPPER WORLD PROJECT
WRF SLOPE STABILITY SECTIONS
PFS DESIGN - WRF STABILITY ANALYSIS
SITE PLAN

wood.

WOOD ENVIRONMENT & INFRASTRUCTURE SOLUTIONS
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PHONE: 602-733-6000

Figure: 1

By: OAS | Date: 11/12/21 | Project No: 17-2021-4024

Drawing Path: G:\Geotechnical\2021 Projects\17-2021-4024 Rosemont_RP21 Private Land Studies\14 CAD\FIG\, Drawing Name: FIG 5-1 WRF MEMO.dwg Plot Date: 06/06/22 - 11:06am

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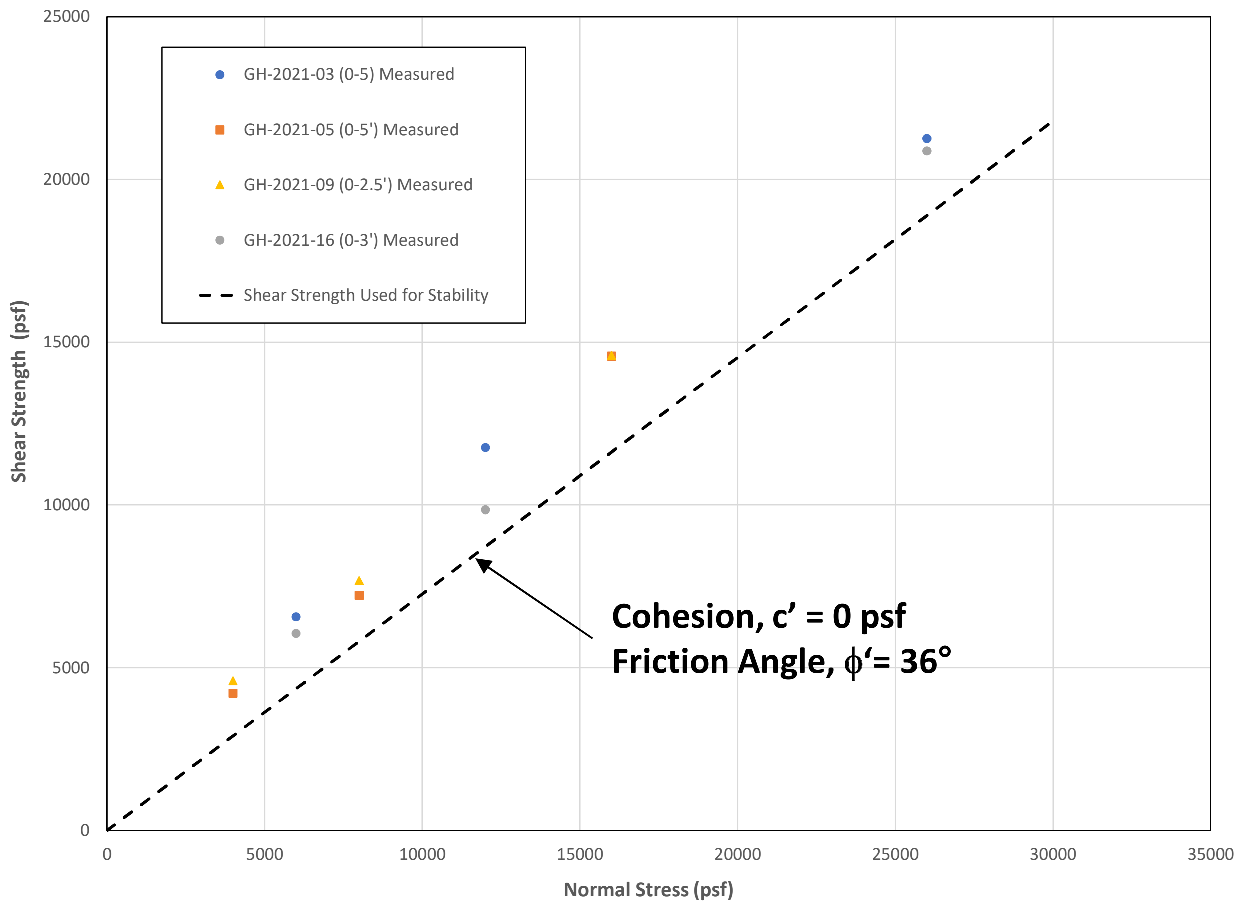

Shear Strength Used for Modeling versus Direct Shear Test Results

- **Foundation Soil**
- **Embankment and Structural Fill**

Rosemont Copper Company	Rosemont Copper World Project PFS Design – WRF Stability Analyses
Summary of Direct Shear Tests on Foundation Soils	
wood. **Wood Environment & Infrastructure Solutions, Inc.**	Figure 2 PROJECT NUMBER: 17-2021-4024 SCALE: N/A DATE: NOV 2021

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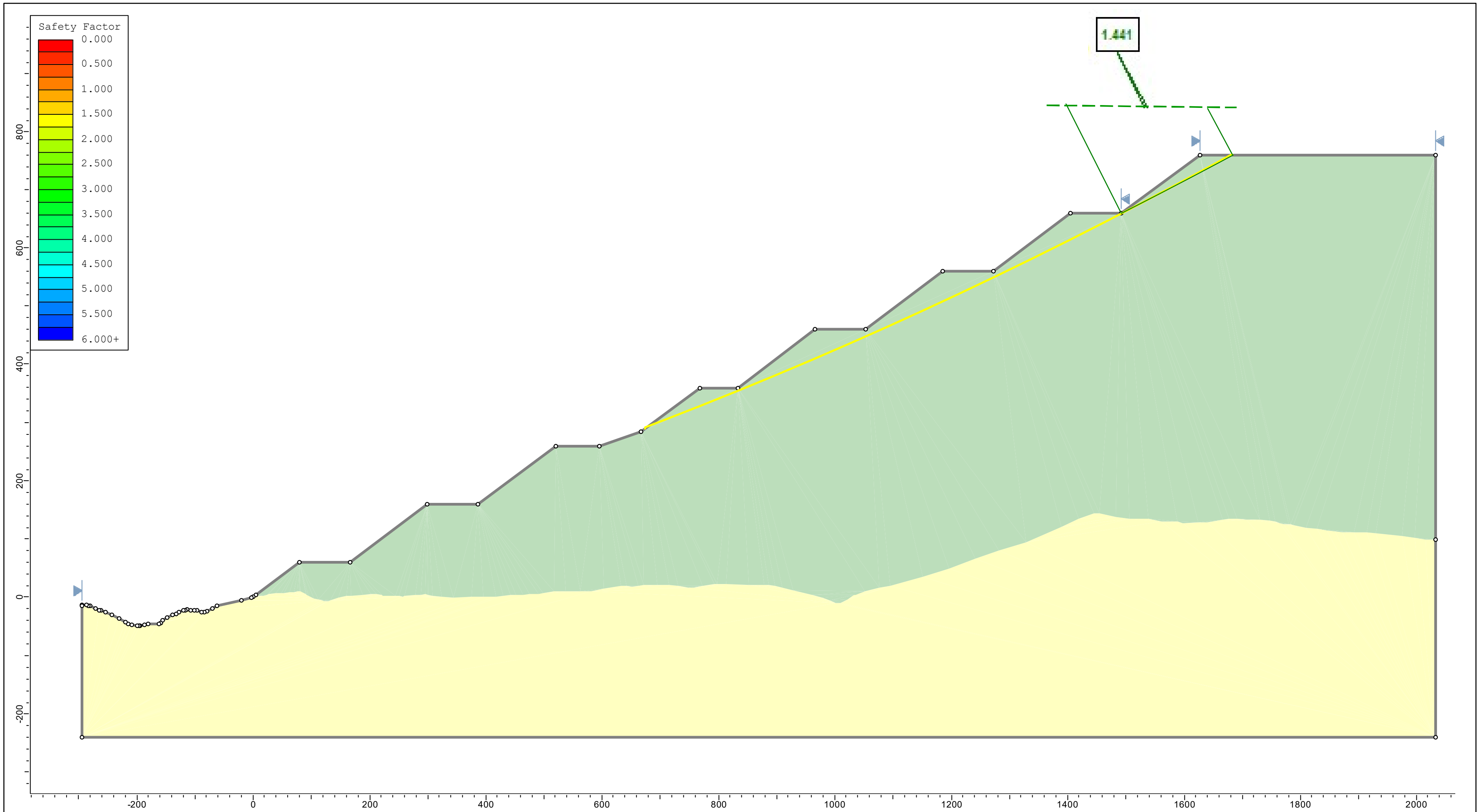

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation		125	Mohr-Coulomb	0	36	None	0
Waste Rock		125	Mohr-Coulomb	0	37	None	0

Static Condition
Circular Failure
Minimum FOS = 1.44

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Rosemont Copper World Project
PFS Design – WRF
Stability Analyses

Section WRF01 – Static

wood.

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Figure 3

PROJECT NUMBER: 17-2021-4024

SCALE: N/A

DATE: NOV 2021

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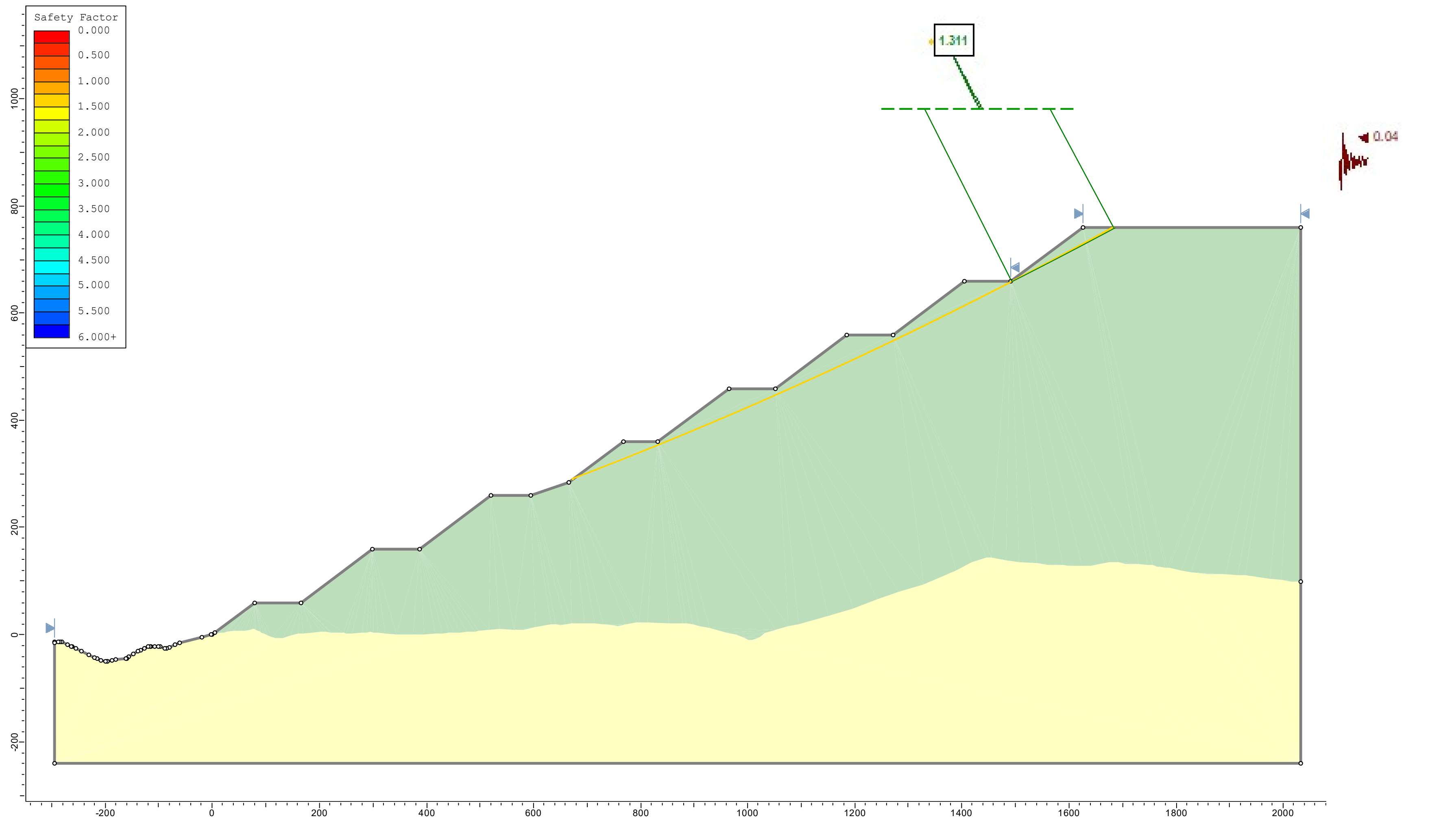

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation		125	Mohr-Coulomb	0	36	None	0
Waste Rock		125	Mohr-Coulomb	0	37	None	0

Pseudo-Static Condition (k = 0.04)
Circular Failure
Minimum FOS = 1.31

Rosemont Copper Company	Rosemont Copper World Project PFS Design – WRF Stability Analyses

Section WRF01 – Pseudo-Static

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Figure 4			
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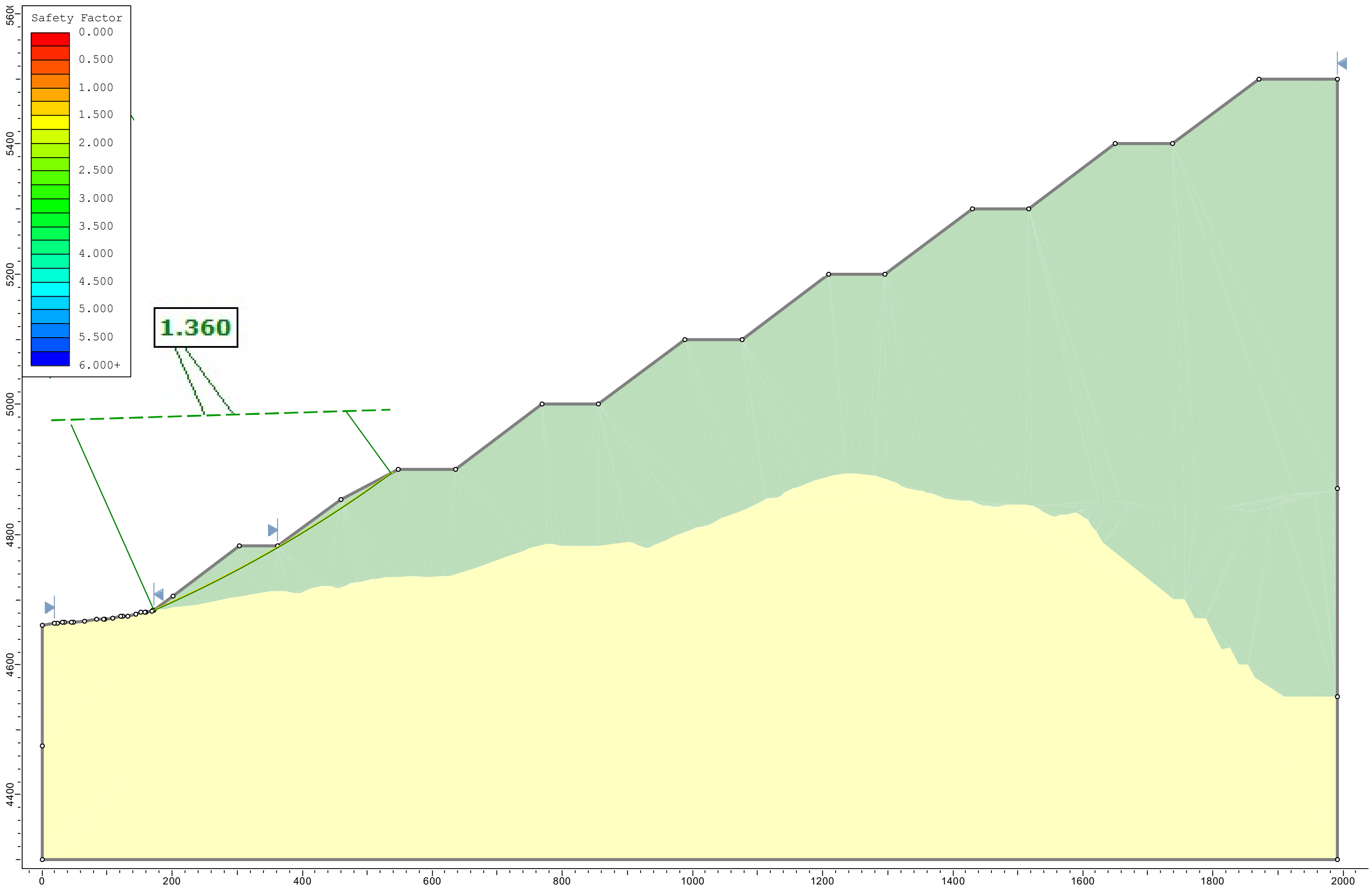

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation		125	Mohr-Coulomb	0	36	None	0
Waste Rock		125	Mohr-Coulomb	0	37	None	0

Static Condition
Circular Failure
Minimum FOS = 1.36

Rosemont Copper Company	Rosemont Copper World Project PFS Design – WRF Stability Analyses
Section WRF02 – Static	
wood. **Wood Environment & Infrastructure Solutions, Inc.**	Figure 5 PROJECT NUMBER: 17-2021-4024 SCALE: N/A DATE: NOV 2021

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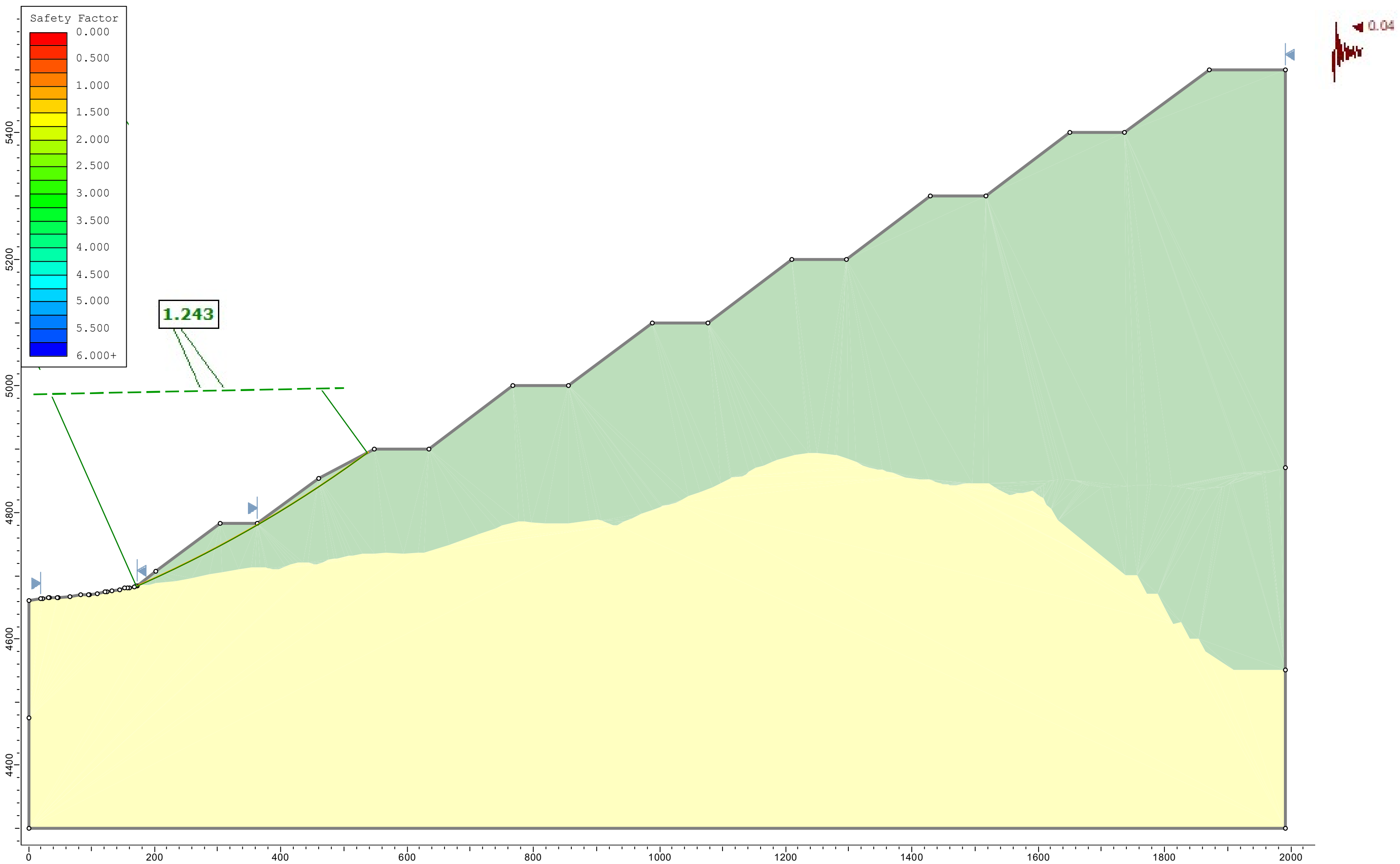

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation		125	Mohr-Coulomb	0	36	None	0
Waste Rock		125	Mohr-Coulomb	0	37	None	0

Pseudo-Static Condition (k = 0.04)
Circular Failure
Minimum FOS = 1.24

Rosemont Copper Company	Rosemont Copper World Project PFS Design – WRF Stability Analyses

Section WRF02 – Pseudo-Static

wood. **Wood Environment & Infrastructure Solutions, Inc.**

Figure 6			
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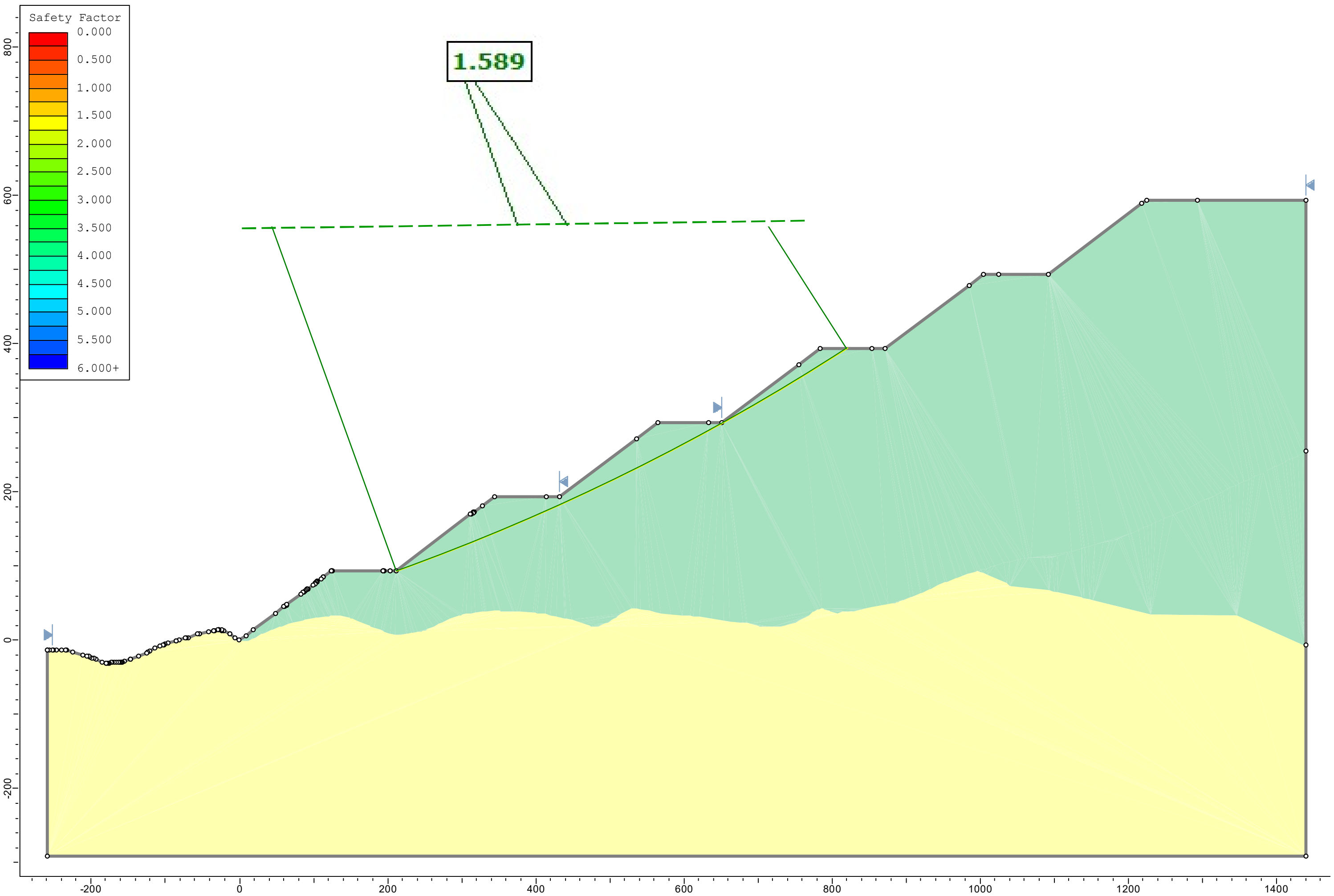
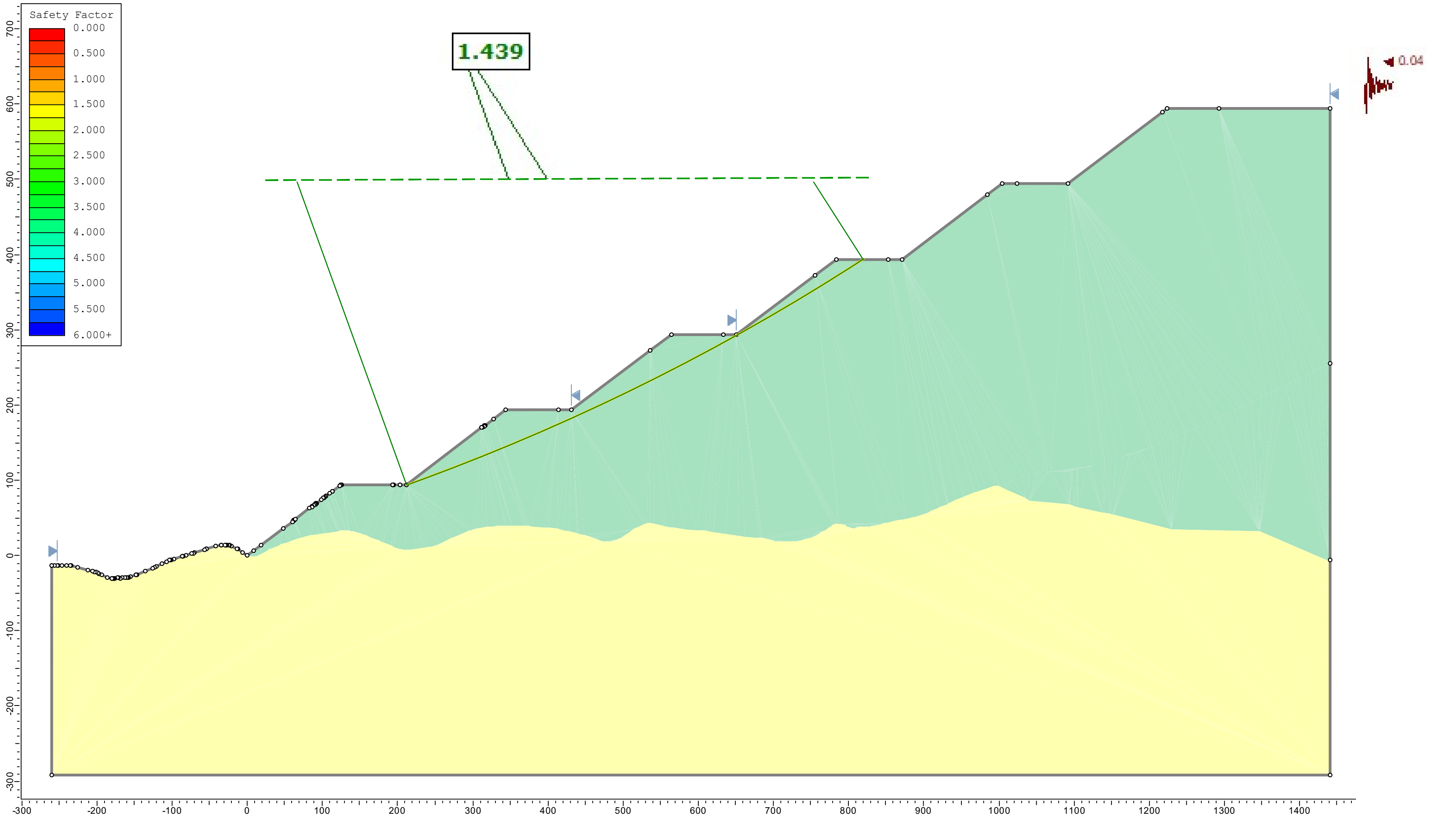


Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation		125	Mohr-Coulomb	0	36	None	0
Waste Rock		125	Mohr-Coulomb	0	37	None	0

Static Condition
Circular Failure
Minimum FOS = 1.59

Rosemont Copper Company	Rosemont Copper World Project PFS Design – WRF Stability Analyses
Section WRF03 – Static	
wood. **Wood Environment & Infrastructure Solutions, Inc.**	Figure 7 PROJECT NUMBER: 17-2021-4024 SCALE: N/A DATE: NOV 2021



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation		125	Mohr-Coulomb	0	36	None	0
Waste Rock		125	Mohr-Coulomb	0	37	None	0

Pseudo-Static Condition (k = 0.04)
Circular Failure
Minimum FOS = 1.44

Rosemont Copper Company

Rosemont Copper World Project
PFS Design – WRF
Stability Analyses

Section WRF03 – Pseudo-Static

wood.

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Figure 8

PROJECT NUMBER: 17-2021-4024

SCALE: N/A

DATE: NOV 2021

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